NASr-21(01)

47p

[redacted]

[redacted]

010

MEMORANDUM
~~RM-3877-NASA~~
~~SEPTEMBER 30, 1963~~

UNPUBLISHED PRELIMINARY DATA

FACILITY FORM 602

N65 16435	
(ACCESSION NUMBER)	(THRU)
47	1
(PAGES)	(CODE)
CR 55290	07
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

HIGH-CAPACITY SUBMARINE TELEPHONE CABLES: IMPLICATIONS FOR COMMUNICATION SATELLITE RESEARCH AND DEVELOPMENT

[redacted]

R. T. Nichols

This research is sponsored by the National Aeronautics and Space Administration under Contract No. NASr-21. This report does not necessarily represent the views of the National Aeronautics and Space Administration.

PREPARED FOR:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GPO PRICE $ ______

OTS PRICE(S) $ ______

Hard copy (HC) 2.00

Microfiche (MF) .50

The RAND Corporation
SANTA MONICA • CALIFORNIA

NASA Contract NASr-21(01)

MEMORANDUM
Rept. RM-3877-NASA, Rev.)
SEPTEMBER 30, 1963
NASA CR-55290

HIGH-CAPACITY SUBMARINE TELEPHONE CABLES: IMPLICATIONS FOR COMMUNICATION SATELLITE RESEARCH AND DEVELOPMENT

R. T. Nichols 30 Sep. 1963 47p refs

[redacted]

This research is sponsored by the National Aeronautics and Space Administration under Contract No. NASr-21. This report does not necessarily represent the views of the National Aeronautics and Space Administration.

7392004

The RAND Corporation
1700 MAIN ST. • SANTA MONICA • CALIFORNIA

CONTENTS

PREFACE

This RAND Memorandum is a result of a study of the economic implications of communications satellites conducted by The RAND Corporation for the National Aeronautics and Space Administration under contract No. NASr-21(01).

The purpose of the present Memorandum is to assess the implications of high-capacity cables on the requirements for future communications satellite research and development by NASA.

The development of inexpensive submarine telephone cables has been an objective of the telephone companies of the world for many years. Writing in 1956, Mervin J. Kelly of the Bell Telephone Laboratories and Sir Gordon Radley of the British Post Office pointed out that "since...December, 1953...considerable progress has been made in the development and use of transistors. The low power drain and operating voltage required will make practicable a cable with many more submerged repeaters than at present. This will make possible a further widening of the transmission band which could provide for more telephone circuits with accompanying decrease in cost per speech channel or the widened band could be utilized for television transmission. Much work, however, is yet to be done..." [<u>The Bell System Technical Journal</u>, January 1957, pp. 3-4].

Early in 1963 a representative of the Bell System announced that a transistorized submarine telephone cable with a capacity of 720 voice channels was expected to be ready for use by about 1966. This announcement has provoked much speculation about the impact of the new cable on plans for commercial satellite communications. (See, for example, the open letter of April 2, 1963 from General David Sarnoff, Chairman of the Board of the Radio Corporation of America, to Mr. Leo D. Welch, Chairman of the Communications Satellite Corporation.)

The author wishes to thank RAND colleagues R. N. McKean and E. S. Quade for their helpful comments on an early version of this Memorandum, and gratefully acknowledges the contribution of R. L. Slighton, with whom many of the ideas expressed here originated.

SUMMARY

11457 	16A35

The development of submarine telephone cables has proceeded rapidly since the end of World War II. The capacity of the cable systems has been increased and the costs of service on high-volume routes have been substantially reduced. On the North Atlantic route, which accommodates more than half of the world's intercontinental traffic, cables now essentially developed may in a few years furnish channels at a cost that is only one-fourteenth the cost of channels in the first transatlantic telephone cable, laid in 1956.

The demand for channels provided by any type of communication facilities, for example, communications satellite facilities, depends, among other things, on the costs of channels provided by alternative systems. The main significance of the new cables is that they promise to lower the costs of conventional channels on high-volume routes, thus lessening the demand for communications satellite channels on these routes.

It has often been supposed that communications satellites would be economically attractive, relative to conventional communications facilities, for long distance, over-water, large capacity routes. The emphasis on "long distance" is well-grounded. The reason is that the cost of satellite circuits is independent of circuit length, while the cost of conventional circuits is proportional to circuit length. The emphasis on "over-water" is less well-grounded. The cost of satellite circuits overseas is the same as the cost of satellite circuits overland; on the other hand, submarine cable circuits are probably no more expensive than landline circuits in many areas of the world, and they cost perhaps only twice as much as landline circuits in the United States. Therefore, if satellite communication circuits are competitive with (or markedly cheaper than) submarine cable circuits, they may also be competitive with (or cheaper than) conventional overland circuits. Author

In comparing the costs of different conventional modes of communication for point-to-point service, it is necessary to take account of the capacity of the systems. It would be misleading, for example, to compare the per channel costs of a 10,000-channel landline system with the per channel costs of a 100-channel submarine cable system. The costs of the various modes are in each case a function of capacity. For landline systems, a large percentage increase in capacity implies a large percentage decrease in cost per channel. For submarine cable systems, such a relationship has not been as clearly established, because we have less experience to go on; however, to a first approximation, a relationship of the landline type is also applicable to undersea cable systems. For conventional modes of communication, therefore, per channel costs are substantially lower on high-volume routes than on low-volume routes.

For communications satellite systems, the problem takes a different form. That the satellite systems may have very large channel capacities does not necessarily lead to the conclusion that the most advantageous use of such systems is on high-traffic routes. Unlike conventional systems, satellite systems with suitable multi-access capabilities would be able to serve a varying number and pattern of routes as well as a varying number of channels per route. For such a system the cost of satellite channels for a given route would therefore depend on the demands for channels on all routes served by the system. Hence, for satellite systems, there is no unequivocal cost-capacity relationship between costs per channel on high-capacity and on low-capacity routes. Therefore, the emphasis on "large capacity" for satellite systems does not seem to be as well-grounded as had been thought.

Stress on long distance, over-water, large capacity circuits implies that the primary aim of satellite research is to develop systems capable of providing service on the two or three high-volume overseas routes. Our analysis suggests that there are significant advantages to be expected from the development of satellite communication systems adapted to serve low-volume as well as high-volume routes.

Satellite research and development planning should take account of these advantages and, among other objectives, look for ways of providing inexpensive low-volume service (say, fewer than a hundred channels) over many routes (say, more than fifty).

Other considerations may point in a different direction. There are possible applications of communications satellites that would require a very large number of voice channels; moreover, if it costs a great deal more to develop a satellite system serving non-bulk routes than a system serving bulk routes, the question of a desirable orientation of research remains open.

I. INTRODUCTION

During the course of a debate on communications satellites, in March 1963, the following exchange took place in the House of Commons:

> Mr. Frederick Lee (Newton): In 1956, the cost per circuit mile of laying cable was about £156... With all the bigger cables which have been laid since 1956, the cost has gone down from £156 per circuit mile to £41 per circuit mile, while for the Australia-New Zealand-Fiji-Hawaii-Canada cable ...the estimate is £38 per circuit mile.
>
> Mr. John Rodgers (Sevenoaks): So what?

Mr. Rodgers' question is a very good one. In the main, it is the question that we attempt to answer in this paper. We will start with a survey of submarine telephone cables.

II. THE DEVELOPMENT OF SUBMARINE TELEPHONE CABLES

The first submarine telephone cable was placed under the English Channel in 1891. The distance was short and the water was shallow. It was not until 1921 that the first deepwater telephone cable was placed, between Florida and Cuba, with one voice channel and two telegraph circuits for each direction of transmission.

In 1930, the Bell System and the British Post Office plotted a tentative route for a single voice channel cable across the Atlantic. In present-day dollars, the cost per circuit-mile would have been on the order of $5,000.* This plan and other plans for North Atlantic cables were abandoned, partly because of the improvement in radiotelephony and partly because of the depression. The first commercial radiotelephone circuit between the United States and England had been opened in 1927.

Research on telephone cables was resumed in the 1930s and continued at a modest level during World War II. Since the end of the war, development has been very rapid. The principal problem to be solved was that of devising repeaters (amplifiers) capable of trouble-free operation for a period of 20 years or more at the bottom of the sea. In 1950, the first submerged deepwater repeaters were installed on a cable between Florida and Cuba. They have operated ever since without fault.

Today (1963), two types of long distance deepsea cable are being placed, each capable of providing service over a link as long as 4000 miles. One type, of British design, provides 80 voice channels. The

---

*Throughout this Memorandum, we use "voice channel," "channel," and "circuit" interchangeably, when "channel" and "circuit" are not preceded by a qualifying adjective such as "telegraph." It is standard British practice to use "circuit," although "channel" is not uncommon. In America, all three terms are used, as well as "voice circuit"; both in ordinary speech and in technical journals, a circuit in one sentence becomes a channel in the next sentence. The formal term is "voice grade channel." For our purposes, the only distinction of importance is that between a voice channel and a voice trunk--see Appendix A.

other type, of American design, provides 128 voice channels. The installation cost of each type is about $114 per circuit-mile. (See Appendix B.)*

Cable systems of considerably higher capacity are now very nearly through the developmental stage. One is a British design, using an improved type of electron tube, that will provide about 360 voice channels per cable system. The other is an American design, using transistorized components, that will provide about 720 voice channels per cable system. It is anticipated that the British system will be ready for use by 1966. It now appears that the American system will not be ready for use by 1966 as was expected in February of this year.**

Work on cable components applicable to systems of still larger capacities is in hand. The new British electron tube is suitable for systems with a maximum capacity on the order of 700 voice channels. Transistor development in Britain has followed a slightly different

---

*The fact that the installation cost per circuit-mile of an 80-circuit British cable is the same as the cost per circuit-mile of an American 128-circuit cable is not indicative of the typical relation between cost and capacity. (In this specific case, the cost correspondence can be explained partly by differences in technology and partly by differences in standards.) Typically, the cost per circuit-mile is a function of the capacity of the cable system, decreasing with increased capacity. For example, the cost per circuit-mile of a 24-circuit cable placed in 1962 was over $200. This small-capacity cable was installed primarily for the use of the International Civil Aviation Organization rather than for general commercial use.

**See the testimony of J. E. Dingman, Executive Vice-President of AT&T, at the Hearings before the Subcommittee on Communications of the Committee on Commerce, United States Senate, February 18, 19, and 27, 1963 (United States Government, 88th Congress, 1st Session, Satellite Communications, p. 39). It does appear that Mr. Dingman may have been rushing matters a bit when he suggested a use date of 1966. Work on this specific cable system was not started until early 1962. In the case of other cable systems, there seems to have been a period of two or three years required for development of the system, and another period of two or three years required for manufacture and assembly of the system components. Work on the 128-circuit cable was started in 1957, and the first cable was not placed until six years later, in early 1963.

course from that in America; it now appears that the type of transistor units under development in Britain will be suitable for use in systems up to 1200 voice channels. The maximum number of voice channels obtainable from the American transistor is probably a good deal higher than the 720 voice channels provided in the current system design.

From the technical point of view, in the opinion of some normally conservative experts, there is no serious barrier to the development of cable systems of still larger capacities. From the economic point of view, however, there is serious question whether such development would be worth the cost. In the first place, large reductions in cost per voice channel can be achieved only by vastly expanding the voice channel capacity of the cable system. To give an appreciation of what this means, we focus on the AT&T 720-circuit system. This system, if used to full capacity, would provide channels at a cost somewhat less than one-third of the cost of channels in the 128-circuit system, as explained below. But note that the capacity of the 720-circuit system is over five times the capacity of the 128-circuit system. Similarly, a cable system of the 1970s, if it were to be very much cheaper per channel in percentage terms than the 720-circuit cable, would probably have to have a much greater capacity, on the order of 2000 or 3000 voice channels. The only route for which such a cable system would be suited is the North Atlantic route. However, if 2000 or 3000 circuits were to be provided on the North Atlantic, a better choice than one single cable might well be two or three smaller cables, because of the value of diversification.*

---

*With regard to components, it is hardly possible to distinguish altogether between general developments in the telecommunications art and specific developments in the submarine cable art. Thus, it is conceivable that developments undertaken to satisfy other communication requirements would find applications in submarine telephone cables, perhaps significantly reducing the cost per channel-mile for a given number of channels. As the state of the art now is, the maximum anticipated reduction in costs per channel for a given number of channels is about 20 per cent: for example, the cost of the 128-circuit system might be reduced from $114 per channel-mile to $95 or so.

The other economic consideration that tends to make the future development of 2000-circuit cables questionable is the potential competition from communications satellites. A good deal more must be found out about the costs and capabilities of communications satellites, one would think, before investment in actual development of submarine cables is undertaken.*

As we have suggested, technological advances and innovations have reduced the costs of submarine telephone cables at a remarkably rapid rate since the end of World War II. The first long distance deep-sea cables of American design cost about $450 per circuit-mile; the British and American cables going into service in 1963 cost about $114 per circuit-mile; and high-capacity cables of present design are expected to cost about $32 per circuit-mile.**

No single figure accurately reflects the cost reductions for all routes and for all uses of the cable systems. Because the high-capacity cables are the cheapest cables per voice channel, the cost reduction will be greatest on the routes where the volume of traffic is also high. On high-volume routes, such as the North Atlantic, the trends in cable costs as a function of the type of service supplied are shown in the following tabulation (for details about the derivation of these index numbers, see Appendix B). It should be noted that these index numbers reflect two different effects of technological change. As technology advances, one effect is to lower per channel costs for a given number of channels. Another effect is

---

*The view expressed here is not universally accepted. Some experts stress the point that two competing modes of communication tend to have specific values in different uses, and that there is value in diversification. More is said on this subject in Section IV of this Memorandum. Again, it is conceivable that cable research, although not cable development, might be carried forward more vigorously as a consequence of successful satellite development.

**This figure is appropriate to the AT&T 720-circuit system; it is of course a speculative developmental figure. The system has not yet gone into manufacture.

to provide more channels for a given total cost. In practice, the nature of the technological advances has been such that really big reductions in per channel costs have hitherto been achieved mainly by increasing the number of channels per system.

COST INDEXES OF NORTH ATLANTIC COMMUNICATION SERVICES
(1956-1959 = 100 for each class of service)

	Message Telephone Service (trunks or channels)	Leased Lines (voice channels)	Very Broadband (greater than 4 kc) Service (bandwidth)
1956-1959	100	100	100
1960	42	75	100
1961-1965	17	25	33
720-circuit system (estimated)	7	7	9.5

The trends shown tend to overstate the cost reductions as viewed by the various operating agencies. There are at least two reasons. First, a cost of $32 per circuit-mile for high-capacity cables is relevant only if the cable is used at its full capacity from the date it goes into service. Second, service is supplied not only by the newest and cheapest systems but also by older cable systems that have higher costs per circuit-mile.

It should also be noted that these data are not intended to reflect the trends in the cost of providing, say, telephone message service to the customer. They do show that the cost of overseas circuitry will be very much less in the future than in the past. However, the cost of providing overseas message service comprises many elements, of which the cost of overseas circuitry is only one.

As the cost of submarine telephone cables has been reduced, the number of cables placed in service has increased. In fact, today (1963) the placing of submarine telephone cables is proceeding at a very high rate. The best illustration of the growth in the cable business and of the expectations for continued growth is provided by the recent increase in the number of cable-laying vessels. From 1946, when it was built, until 1961, the world's first and foremost cable ship was the Monarch, owned by the British Post Office. In 1961-1963, four additional cable-laying vessels were completed: the Alert, another Post Office vessel; the Neptun, owned by the United States Underseas Cable Corporation, a subsidiary of Felten & Guilleaume Carlswerk AG, Phelps Dodge Corporation, and the Northrop Corporation; the Mercury, owned by Cable and Wireless, Ltd., a British concern; and the Long Lines, owned by AT&T.

According to present plans, by 1966, cables will link Western Europe, northern Africa, North America, the northern part of South America, Eastern Asia (Japan, the Philippines, Hong Kong, Malaya), New Zealand, Australia, and North Borneo. There will be several cable systems in the Caribbean, a cable to Bermuda, and many cable systems in the North Sea.*

Submarine telephone cables cost very little to operate and maintain. In consequence, cables already installed will provide an exceptionally economical means of communication throughout their service life. The service life of cables is conventionally described as 20 years, but the actual life will probably be 30 to 40 years.*

In summary: the new high-capacity submarine telephone cables represent a continuation of the rapid development of cable systems since the end of World War II. The initial investment cost of the 720-circuit cable is now estimated to be $32 per channel-mile, less than one-third the investment cost per channel-mile of the cables now being placed. The operating and maintenance costs of cable systems are trivial. Cables installed may provide service for as long as 40 years.

---

*For additional detail, see R. T. Nichols, Submarine Telephone Cables and International Telecommunications, The RAND Corporation, RM-3472-RC, February 1963.

Apart from the impact on costs, the fact is of little significance that the voice-channel capacity of the 720-circuit cable is over five times the capacity of existing cable systems. With the exception of television transmission, there is no function that can be performed by a 720-voice-channel cable that cannot be performed by a 48-voice-channel cable. A 720-circuit cable could be equipped to carry television on a real-time basis, but it is far from certain that it would be so equipped. The effective demand for intercontinental instantaneous television is likely to be small,* the cable must be shut down for all other purposes if it carries TV, the cost of developing the specialized equipment necessary to permit the cable to carry TV is about $5,000,000, and the cost of manufacturing and installing this equipment is about $1,500,000 per cable system.

It is technically possible to apply the TASI technique to any cable system, and thereby to increase the message-carrying capacity of the system substantially. For example, if in a 720-circuit system, 500 circuits were allocated to the carrying of telephone messages and 220 circuits to all other purposes, the application of TASI to the 500 message-carrying circuits would increase the number of voice trunks from 500 to about 1000. For cost reasons, however, it is unlikely that TASI would be so applied. (See Appendix A.)

---

*See the discussion in R. L. Slighton, The Market for Overseas Telecommunications in 1970, The RAND Corporation, RM-3831-NASA, September 1963, pp. 54-56.

III. LANDLINE COSTS AND SUBMARINE CABLE COSTS

In the preceding section we discussed submarine telephone cable costs in terms of the initial investment cost per circuit-mile. For the purpose of comparing the relative costs of the various types of cable systems, investment cost per circuit-mile is a satisfactory measure. The reason is that the recurring or maintenance and operating costs of cable systems are insignificant.*

In comparing the costs of landline microwave systems (or of communications satellite systems) with the costs of submarine telephone cables, the initial investment costs alone are quite unsatisfactory. The reason is that the recurring costs of the radio systems are substantial. According to data supplied by AT&T, annual operating and maintenance costs of the radio equipment on the TD-2 microwave system are approximately equal to 10 per cent of the initial investment cost; annual operating and maintenance costs of the channelizing equipment on the TD-2 system are approximately equal to 8 per cent of the initial investment cost. (The annual operating and maintenance costs for submarine cables are less than 1 per cent of the initial investment cost.)

Both initial investment and recurring operating and maintenance costs can be expressed as equivalent level annual costs, once an appropriate rate of discount is selected.** We prefer to use a rate of 15 per cent, in part because there is evidence that rates on this order characterize returns on private investment today. Other rates

---

*This statement is applicable without qualification to AT&T cables on routes such as deepwater routes where it may be anticipated that breaks in the cables caused by trawlers or icebergs will be nil or negligible. An example is the route from California to Hawaii, where the cable placed in 1957 has never been broken. On the North Atlantic route, existing cable systems run via Newfoundland, and are subject to trawler and iceberg breaks. However, future North Atlantic cable systems in which AT&T has part ownership have been designed or probably will be designed to follow a deepwater route (see Appendix D), and for these systems breaks should be negligible.

**For an explanation of the derivation of level annual costs, see Appendix C.

of discount are defensible. A high rate, such as 15 per cent, increases the equivalent annual costs of submarine telephone cables relative to microwave systems, and the costs of microwave systems relative to communications satellite systems; a low rate, such as 8 per cent, increases the costs of radio systems relative to submarine cable costs.

The level annual cost per channel per nautical mile of TD-2 microwave systems, including channelization costs, is about $2.40. This figure applies to a system designed for a capacity of 720 voice channels and for point-to-point service between a pair of terminals 2000 miles apart. The annual cost per circuit-mile of the large-capacity submarine telephone cables would be about $5.00. The annual cost per circuit-mile of the submarine cables being placed today, with 80 or 128 voice channels, is about $18.00.*

In the past, one development after another has reduced the cost and increased the quality of domestic long-lines transmission. Transmission costs have been reduced relative to local costs, with the result that distance has become less and less a factor in the total costs of long distance telephone calls. Developments now under way, for example in the application of transistorized components to (land) cable, promise continued reductions in landline transmission costs.**

To compare the costs of different modes of communication for point-to-point service, it is necessary to take account of the capacity of the systems. It is misleading, for example, to compare the per channel costs of a 10,000-channel landline system with the per channel costs of a 100-channel submarine cable system. The costs of the various modes are in each case a function of capacity. A

*At an 8 per cent per year rate of discount, the equivalent level annual cost per circuit-mile is about $1.90 for the TD-2 microwave system, about $3.20 for the large-capacity cable, and about $11.40 for the cables now going into service.

**At the present time, for circuits within the United States, the costs of radio-relay systems are somewhat less than the costs of land cable systems. With reference to Figure 1 below, there are in fact two parallel lines applicable to domestic systems, the higher one representing landline cable costs and the lower one landline microwave costs.

rough rule of thumb is that the annual cost per channel of communication facilities in domestic use in the United States (excluding terminal costs) is proportional to $n^{-2/3}$, where n is the number of channels.* In other words, cost per channel (c) is related to the number of channels on a single system by a function of the type: $c = an^{-k}$, where a is a dimensional constant and k is on the order of 2/3. Another way of looking at it is that for a given percentage increase in the number of channels, the percentage decrease in cost per channel is constant. Such a function has not been clearly established for submarine cable systems, because we have less experience to go on, and because the costs actually obtainable reflect not only increased capacities but also improvements that reduce costs for a given capacity. However, to a first approximation, a function of this type is applicable to submarine telephone cable systems, at any rate for the capacities now in prospect; and, very roughly indeed, it appears that the value of k appropriate to such systems is also on the order of 2/3.

For communications satellite systems, the cost-capacity relationship is more complex. For a specific link, the costs per channel depend not only on the capacity of that link but also on the number and the capacity of other links in the system. This point will be discussed in more detail in Section IV.

It may be asked: why compare landline costs with overseas costs, in view of the fact that landline facilities can be used only over land, and submarine cable facilities only under sea? The main purpose is to establish that the costs of oversea facilities and overland facilities, for comparable capacity, can be expected to be of the same order of magnitude. We will want this result in the following section where our interest lies in part in the possibility of substituting communications satellite facilities for both

---

*S. Reiger and W. Meckling, Economic Aspects of Communication Satellite Systems,"The RAND Corporation, P-2396, September 1961, p. 9. This paper is also the source for the landline curve shown in Figure 1 below.

conventional overseas facilities and conventional overland facilities. A subsidiary reason for comparing landline and overseas costs is that on the important North Atlantic route, landline is substitutable for cable over part of the route. (See Appendix D.)

One of the main ideas of this section is that the ratio between costs of overseas circuits and costs of overland circuits is to a first approximation a constant that remains fixed as the number of circuits is varied. This may be shown in diagram form. See Figure 1, which shows comparative annual costs as a function of the number of circuits, both for submarine telephone cable circuits and for overland circuits within the United States. The curves shown are intended only to illustrate the ideas involved; and, as a practical matter, it should be recognized that the curves may not apply where capacities are quite small or extremely large. The curve for submarine systems is a projection based on the cost estimates already discussed, while the curve for overland systems represents actual experience. For purposes of illustration, the figure is limited to the range between 100 and 1000 channels; but for overland systems experience confirms the validity of the curve for capacities up to almost 10,000 channels.

It should be noted that the vertical index in Figure 1 refers to level annual costs per channel provided by a complete new system, on the assumption that each channel provided is sold. This assumption is made for convenience in comparison, and it is an assumption that must be kept in mind. For example, the cost per channel for the 128-circuit cable system on a route where only 64 channels are sold is double the cost per channel on a route where 128 channels are sold. Similarly, if a 720-circuit system were applied to a route where it is anticipated that about 128 channels would be sold, the cost per channel would be higher than it would be if a 128-circuit system were applied to the route. A less obvious point is that, when a new system is introduced, the number of channels initially utilized is almost always less than the number provided by the nominal capacity of the system; typically, there is a build-up period, during which the output of the system is a function of the demand for channels.

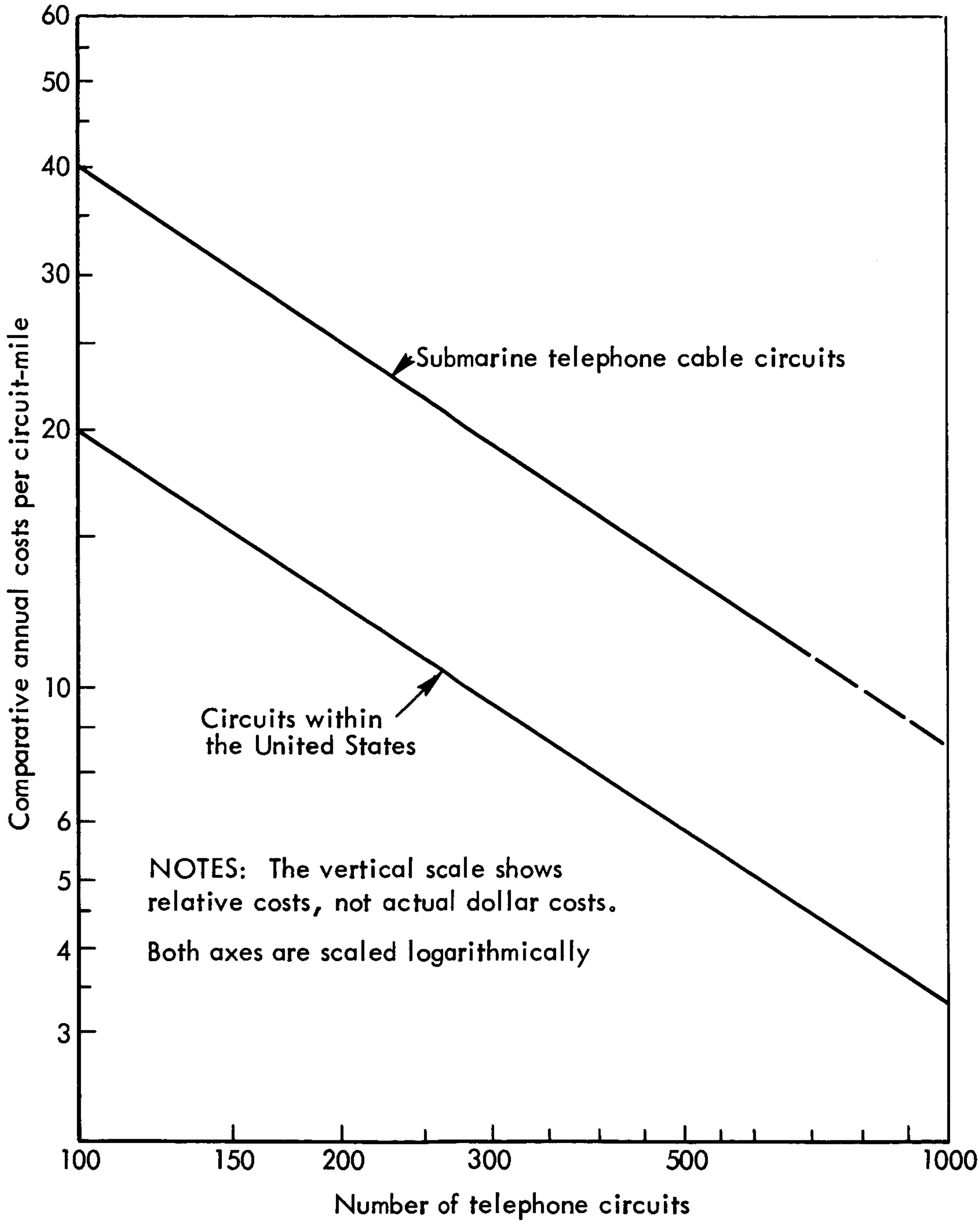

Fig. 1 — Comparative annual costs per circuit-mile as a function of the number of circuits

The effect on cost per channel of introducing a build-up period into the calculations can be quite startling; for example, the actual cost per channel may be more than double the cost that would apply if the system were used to full capacity from the outset.*

---

*See, for example, W. H. Meckling, Communications Satellites: Supplemental Information on the Cost Estimates Given in Research Memorandum RM-2709-NASA, The RAND Corporation, RM-2778-NASA, June 1961, pp. 5-8.

IV. IMPLICATIONS FOR COMMUNICATIONS SATELLITE RESEARCH AND DEVELOPMENT

The demand for channels provided by any type of communication facilities (for example, communications satellite facilities) depends, among other things, on the costs of channels provided by alternative systems. The main significance of the new cables is that they promise to lower the costs of conventional channels on high-volume routes, and therefore to lessen the demand for communications satellite channels on these routes. This statement is meaningful whether or not high-capacity cables are ever actually installed. A mode of communication must meet the competition not only from existing competitors but also from the alternative systems that could be brought into being at the time.

It has often been supposed that the long-term prospects of satellite communication systems are sensitive to the installation of even a single high-capacity cable system. The reason given is that cable systems already installed could supply channels at very low operating cost. That such channels could be provided at very low cost is true. However, what is much more important in the long run is the high rate of growth of telecommunications demand, which is such that additions to demand promise to dwarf present demand. In addition, reductions in the price of telecommunications services could lead to increases in message volume that would soon swamp the capacity of even a 720-circuit system. Therefore, our view is that the implications of the development of high-capacity submarine telephone cables for satellite research and development are not dependent on the future installation of one or two high-capacity cable systems.*

Moreover, as we have already noted, telecommunications concerns place a high premium on being able to furnish continuous, uninterrupted service, and continuity of service is enhanced if communications

*The implicit assumption of this paragraph is that communications satellite systems would be of value principally in providing <u>overseas</u> connections. This is an assumption that we question below.

can be carried over different types of facilities, subject to different kinds of hazards. Again, the common carriers tend to stress the likelihood that one mode of communication will be cheaper for one purpose and the other mode cheaper for another. In other words, the two kinds of services are not perfectly substitutable for each other.

It follows that the demand for cable channels is less sensitive to the costs of potential satellite systems than might otherwise be supposed. It is likely, therefore, that in the next few years the British and the Americans will continue with their cable plans, even though there seems to be a good prospect for inexpensive satellite channels.

Similarly, the demand for overseas communications satellite channels is less sensitive to the costs of actual or potential cable systems than might otherwise be supposed. However, the costs of high-capacity cable channels do give a rough indication of the competition that satellites must meet on high-volume routes. If a 720-circuit cable system is used from the outset to full capacity on each route, it would provide voice channels at an annual cost of $17,500 on the North Atlantic,* of $11,000 to Hawaii, and of $5,500 to the Caribbean.

We now consider the impact on the individual consumer of cost reductions for transmission service on overseas routes. For this purpose, the estimates of costs just given are useful and relevant.

What the individual consumer is buying from the common carriers, when he sends an overseas message or places an overseas telephone call, is transmission services overseas (the services provided by submarine cables or by communications satellites) <u>plus</u> a variety of

---

*This figure is based on an assumption about the length of the North Atlantic cable route. See Appendix D. It is to be noted that these cost estimates, as well as the other estimates of costs throughout this Memorandum, exclude costs, such as overhead costs, that are common to cable systems and satellite systems alike.

other services (for example, transmission of his message from the originating station to the overseas gateway point, transmission of the message from the overseas gateway point at the other end of the line to the intended recipient, switching services at various points along the route, operator services, and billing services). The costs of the miscellaneous services are substantially independent of the mode of overseas transmission. The impact on the individual consumer of reductions in the costs of overseas transmission services depends on the relation between the costs of the overseas transmission services and the costs of the other services.

In the case of telegraph services, it has already been recognized that the impact of communication satellites on the individual consumer would be relatively minor. The point has been made by Reiger and Meckling: "with telegraph...long-line transmission costs are a relatively small proportion of the total cost of a message; reductions in transmission costs will not appreciably affect the cost per message."*

In the case of telephone message service, the impact on the consumer of reductions in overseas transmission costs depends on the traffic per route. For the high-volume North Atlantic route, if a 720-circuit cable were in place and used to full capacity, the overseas circuitry component of the cost of an average length (7-$\frac{1}{2}$ minute) telephone call would be about $2.30.** Those components of the cost of overseas calls that are not associated with overseas circuitry would be about $4.60.*** If communications satellite channels could

---

*S. Reiger and W. Meckling, op. cit., p. 13.

**With level annual costs of $17,500 per channel and an annual volume of 7,500 calls of average length, the transmission cost per call is ($17,500)/(7,500) = $2.33. The number of messages per channel is a variable depending in part on the average length of call and in part on the speed of service. According to Slighton (op. cit., p. 37), the AT&T target is 25 messages per channel per "business day," or 7,500 messages per channel per year.

***The costs of the miscellaneous services are also being reduced, through such innovations as direct operator dialling of overseas numbers. The estimate of $4.60 is intended to represent the costs about five years hence. It should be noted that we focus here on the be supplied at, say, half the cost of high-capacity cable channels, the effect would be to reduce the cost of a $7\frac{1}{2}$ minute call from about \$6.90 to about \$5.75, a reduction of 17 per cent.

This analysis does not, of course, apply to routes where the traffic is not heavy enough to warrant the installation of high-capacity cables, and where, therefore, the overseas transmission costs are high. On such routes, the cost of providing overseas circuitry represents a large part of the total cost of an overseas telephone call, and if there were substantial reductions in overseas transmission costs, the total costs would fall by much more than 17 per cent. If communications satellites can provide channels on these routes at half the cost of conventional channels, it is here that the impact on the individual consumer will be large.

The immediate decisions to be made by those responsible for communications satellites are in the field of research and development: should research and development be continued, and, if so, how should it be oriented? The first part of this question has already been answered in the affirmative. The Communications Satellite Act of 1962 states that "...it is the policy of the United States to establish... as expeditiously as practicable a commercial communications satellite system, as part of an improved global communications network...." A very similar goal was expressed in a Resolution adopted by the House of Commons on March 29, 1963:

> Resolved: That this House mindful of the fact that ever-improving communications are an absolute prerequisite for expanding trade both internal and external...calls upon Her Majesty's Government to announce plans for a general improvement in communications and in particular for the provision of a British and Commonwealth telecommunications satellite; and further calls upon the Government to treat this matter as one of great urgency....

It is the orientation of research and development that is affected by developments in the costs of conventional communications

---

<u>relation</u> of the miscellaneous costs to the overseas transmission costs; our estimates are presented for the purpose of indicating this relationship, and not as guides to the absolute costs that may be incurred by communications concerns in supplying overseas service in the future.

facilities. If research and development decisions have been based on the old estimates of submarine cable costs, then the information on these costs presented here suggests a change in the allocation of effort. The action called for is to assess research and development activities with respect to their relative contributions to the provision of high-volume overseas services and to the provision of other services. Additional effort should be devoted to those activities leading towards knowledge of and development of components and systems that have the following functions:

(a) The provision of communications service to and within those areas of the world served only by HF radiotelephone, radiotelegraph, or submarine telegraph cable, in order to improve the quality of the service.

(b) The provision of channels on low-volume cable routes, where the reduction of costs could be most apparent to the individual consumer.

(c) The provision of at least a few satellite circuits on all routes served by cable, in order to provide an alternative in the event of cable failure.

(d) The provision of a small number of <u>direct</u> circuits between the capitals of the world. One of the weaknesses of submarine telephone cables is that communication to all except a very few countries necessarily passes through another country. For example, by 1965, the United States will have direct cable connections only to two countries of Western Europe, Britain and France. All the other countries of Western Europe will be reached via Britain or France.

These functions point in the direction of service between a large number of points (say, fifty to a hundred), with many of the links having a rather small number of voice channels (say, fewer than a hundred). The contrast with the function of providing ordinary commercial service between the United States and Western Europe is very marked. For the latter purpose, what is needed is a large number of voice channels between a pair of points -- the type of service for which submarine cables were designed.

Satellite systems should be designed to exploit the weaknesses, not to meet head-on the strengths, of submarine telephone cables. The keynote here is flexibility. A cable system is limited to point-to-point transmission, from one point in North America, say, to one point in Europe. For cable systems, the best routes are those where the full capacity of the system can be used from the outset, or very nearly from the outset, and where the demand will not slacken for many years. What if the pattern of demand shifts, from one route to another route? The cost of uprooting and moving submarine telephone cables is probably prohibitive, nor can a new system be installed without heavy initial cost. On the other hand, the techniques of satellite communication are such that a shift in traffic patterns probably could be accommodated at relatively little cost; satellite systems offer flexibility through frequency-sharing and time-sharing. Again, as we have already suggested, a weakness of cable systems is that communication to all except a very few countries passes through another country. Satellite systems offer the possibility of direct connections with all parts of the world, reducing hazards of direct physical interference from changing administrations in intermediate countries.

Although communications satellites are no less able to carry messages overland than overseas, attention from the first (1959-1960) was directed towards their use as overseas carriers. The reason is not hard to find. Costs of landline communication at that time were very much less than costs of submarine cable communication. The price of a three-minute daytime person-to-person call was (and is) \$3.50 across the continental United States, while the price of a similar call to England was (and is) \$12.00. On the other hand, communications satellites could provide service at the same cost overseas as overland. Hence, to the extent that communications satellites were thought to have a cost advantage over conventional facilities, the advantage appeared to be greatest in the overseas market.

Our review suggests that conventional facilities will be able to provide service on overseas routes at costs much closer to landline costs than had previously been supposed. In many areas of the world, landline costs are much higher than they are in the United States, and in the United States, as we have noted in Section III, it appears that landline costs are as much as half of overseas costs. Communications satellites are able to supply overland as well as overseas markets, and the traffic volume in overland markets is much heavier than that in overseas markets, and is likely to remain so. Therefore, if communications satellites compete successfully with submarine cables, they may also compete successfully with overland systems, at least in certain parts of the world.

It is occasionally argued that communications satellites are peculiarly fitted for service on high-volume routes. Satellite systems will offer channel capacities that are large relative to the capacities of existing conventional overseas systems and that are comparable to the capacities of conventional high-volume long-distance overland systems. Therefore, it is argued, to the extent that communications satellites have an advantage over conventional facilities, the advantage will be greatest on the high-volume routes.

In our view, the argument just advanced is open to serious question. It is true that for conventional point-to-point communications systems, a system that provides, say, 600 channels may be regarded as suitable for a route over which the traffic would utilize about 500 channels, whereas a 600-channel system would be regarded as unsuitable for a route over which the traffic would utilize only about 50 channels. There are two reasons for this. First, when conventional facilities (submarine cables, for example) are once installed for a given route, there is no low-cost method by which any part of the capacity can be shifted to serve another, quite different, route. Second, the larger the capacity installed, the larger the over-all system cost for the route. Thus in our example, where the traffic would utilize only about 50 channels, the 600-channel system would have a large excess capacity; this excess would not be used on the route and could not be used elsewhere; and the cost per utilized channel would be higher than for a system of smaller capacity (say, 100 channels). (Of course, as shown in Fig. 1, the smaller capacity system would have a higher cost per available channel than the 600-channel system.) The point here is the important distinction between cost per channel available and cost per channel utilized. To minimize the cost per channel utilized, it is necessary with conventional facilities to install low-capacity systems for low-traffic routes, and high-capacity systems for high-traffic routes. But it appears to be a non sequitur to conclude that the most advantageous use of satellite systems (with a very large over-all system capacity) must necessarily be on the high-traffic routes.

With satellite communications systems, the problem takes a different form. Unlike a conventional system, a satellite system with suitable multi-access capabilities would have considerable flexibility in serving a varying number and pattern of routes, and, within limits, would be able to vary the number of channels available for any given route. Moreover, the cost of satellite channels for a given route depends not only on the number and capacity of other routes, but also on the demands for channels on all routes served by the system.* Thus for satellite systems there appears to be no unequivocal cost-capacity relationship between costs per channel on high-capacity and on low-capacity routes. This would seem to be so at any rate if, as appears likely,** ground station costs per channel are relatively low compared to the costs per channel of the orbiting systems.

The cost-capacity relationship for conventional systems is such that a large percentage increase in capacity implies a large percentage

---

*For a discussion of the problem of satellite costs per route, see J. R. Minasian, Telephone Rates, Queues, Costs: Some Economic Implications for Analyzing Fluctuating Demands, The RAND Corporation, RM-3829-NASA, September 1963, pp. 16-22; and L. L. Johnson, Joint Cost and Price Discrimination: The Case of Communications Satellites, The RAND Corporation, P-2753-1, July 1963, passim. Johnson notes that if demand elsewhere is sufficiently great, the cost of service (excluding ground station cost) on a specific route may be zero (p. 20).

**Except possibly for ground stations for a very small number of channels, say less than 10 or 12.

decrease in cost per channel; specifically, according to the slope of the curves shown in Fig. 1, a doubling of capacity on a given route implies a 37 per cent decrease in the cost per channel available. The question is, what is the relevant cost-capacity relationship for satellite systems? We would like to know, for example, whether in a satellite system with a number of routes the cost per channel on a 200-channel route is 37 per cent less than on a 100-channel route, or 20 per cent less, or 50 per cent less, or whatever it may be.

As indicated above, there are serious difficulties underlying the question of cost allocations among the various routes of a satellite communications network. A solution that has, at least, the advantage of simplicity is to divide the cost of the orbiting system equally among all the channels utilized. If this were done, for a multi-route communications satellite system of given over-all capacity, a shift of channels from one route to another would not in itself change the average orbiting system cost per channel on any route. In other words, the cost-capacity curve for this component of cost alone would be plotted as a horizontal line in Fig. 1. This result obtains, of course, only if there are no extra costs involved in redistributing channels among the routes served by the system. The simple cost allocation procedure just described might be adopted by an administrative agency, but, for reasons explained by L. L. Johnson* among others, this procedure would probably not be defensible as the most efficient in strictly economic terms.

If, however, we follow this simple approach, the ground station costs per channel would be added to these costs per channel for the orbiting system. The shape of the cost-capacity curve for the combined costs would depend upon (a) the cost-capacity relationship for ground station facilities and (b) the relative costs per channel of the orbiting and ground station facilities. If the ground station costs per channel were quite low compared with the orbiting system costs per channel, then the combined cost-capacity curve, if drawn on Fig. 1, might well be much shallower than the curve for cables and other

*See Johnson, op. cit., pp. 14-20.

conventional systems. If this is so, it would follow that any cost advantage the satellite system may have over conventional systems would be greater for the low-volume than for the high-volume routes.

For communications satellite research and development, this discussion of cost-capacity relationships has the following bearing. The case for orienting research and development towards serving high traffic routes, insofar as it rests on the supposition that satellite systems are especially qualified to serve such routes rather than low-traffic routes, is open to question. Therefore, if in fact satellite research and development has been directed towards high-traffic routes on the basis of this supposition, it appears that some reorientation is required. We think that more attention should be paid to the problems of providing inexpensive service over a large number of low-volume routes. Part of the problem of serving such routes is the problem of multi-accessibility, and on this specific problem we believe that the need for research is generally understood. Effort should also be devoted to increasing knowledge of the ways to serve inexpensively the many low-volume routes that would be technically possible in a multi-access system.

We would like to emphasize that this analysis is by no means all-inclusive; it is preliminary and in part necessarily qualitative rather than quantitative. A communications satellite research and development effort directed towards non-bulk uses does appear to us to be desirable on the ground stated: it is in the non-bulk uses that communications satellites may have an advantage. Other considerations may point in a different direction. For example, the mandate in the Communications Satellite Act of 1962 to establish a system "as expeditiously as possible" would suggest continued emphasis on bulk routes, if for technical reasons (such as the problem of multiple access) satellite systems capable of serving a few routes can be developed sooner. Again there are possible applications of communication satellites, such as television, that would require a very large number of voice channels per route. If the demand for television transmission develops sufficiently, the conclusion suggested above would have to be modified. Finally, the costs of research and development are to be taken into account. If it costs a great deal more to develop a satellite system serving non-bulk routes than a system serving bulk routes, the question of a desirable orientation of research and development is open.

HIGH FREQUENCY RADIOTELEPHONE FACILITIES

We have already suggested that one function of communications satellites is to provide channels to those areas of the world served only by high frequency (HF) radiotelephone. In this section of the Memorandum, we will consider the point again, following a different approach.

Because of the vagaries of the ionosphere, high frequency telephone circuits are subject to fading, distortion, and complete blackout. Submarine telephone cable circuits are free from these faults (with the exception of blackout due to cable breaks). Telephone conversations last about 20 per cent longer on cable circuits than on HF circuits. There are more telephone conversations on routes equipped with cables, both because more calls are placed and because more calls that are placed are completed. More calls are filed because of the superior quality of speech transmission. More calls filed are completed because of the superior continuity of service.

Telephone service by cable is a different commodity from telephone service by HF radio. Accordingly, in addition to surface mail and airmail, we may distinguish three types of intercontinental communications service that are or should be world-wide: (1) telegraph message service; (2) HF telephone service; and (3) cable-quality telephone service. An ordinary telegram can be sent to practically any point in the world. Telephone service, of some kind, reaches almost everywhere. However, telephone service of good quality is restricted in scope, and if such service is to become world-wide, it seems likely that it will be provided by communications satellites.

It now appears that by 1970 the following areas of the world will be relying in the main on HF telephone service for intercontinental communication:

1. South America, south of the northern tier of countries.

2. Africa, excluding the countries in the northwest. However, if the British complete their once-planned globe-girdling cable network, southern Africa will be served by cable.

3. The Mid-East (Iran, Iraq, Israel, Jordan, Lebanon, Saudi Arabia, Syria, etc.).

4. Mainland China and South Asia (Afghanistan, Pakistan, India, Burma, Thailand, etc.). If the Commonwealth cable is completed, India and Pakistan will enjoy cable service.

5. Various islands. For example, in the Pacific, Tahiti and Samoa; in the Atlantic, the Azores and Ascension Island; in the Caribbean, Hispaniola, and perhaps a few others. The identity of the islands is, however, not important. More and more islands are being connected with the world's cable network; on the other hand, other islands are being furnished with telephone service for the first time by HF radio.

There are now (1963) about 100 HF common carrier telephone circuits serving these various areas.* If high-quality service is available, the number of circuits in use by 1970 would be very much higher. In addition to normal growth, the substitution of high-quality circuits for low-quality circuits tends to increase the volume of message traffic by a factor between 1.5 and 2.** We also expect that the internal communications within many of the countries in these areas will be improved by 1970, in turn leading to a further increase in overseas communications. In sum, we expect that the 1970 demand for overseas service from these various areas (at existing prices) will total at least 300 circuits. This number is about equal to the total number of circuits, both HF and cable,

---

*This is an order-of-magnitude estimate. It is based on the actual number of AT&T circuits to the areas as of January 1, 1963; and on H. M. Flinn's study of the distribution of the world's telephone calls in 1960 ("Estimated Overseas Telephone Message Traffic, 1960," mimeographed by AT&T, October 1961).

**The evidence for this statement is given in R. L. Slighton, op. cit., p. 20.

available to AT&T for long distance overseas service in 1959-1960. We expect a substantial part of this demand to be filled by satellite channels, especially if reductions in cost for low-volume routes can be achieved.

V. CONCLUSIONS

For communications satellite research and development, the main significance of the new high-capacity submarine telephone cables is that on high-volume overseas routes the costs of cable service are potentially about two-thirds lower than had hitherto been estimated. This potential reduction in costs lessens the possible cost advantages of satellites on high-volume routes, while leaving unchanged the possible cost advantages of satellites on other routes. Decisions concerning communications satellite research and development which reflect the earlier (higher) estimates of the costs of submarine cable channels may have led to too much emphasis on the development of satellites for high-volume routes; the estimates presented here suggest that increased effort should be devoted to research leading to the development of components and systems suitable for serving low-volume routes.

This conclusion is strengthened by a re-examination of the nature of the competition between communications satellites and conventional systems:

First, satellite systems, because of their potential multi-access capabilities, and because of the possibilities of frequency-sharing and time-sharing, appear to be inherently more flexible than cable systems. Submarine cable systems are designed in the main to carry a large volume of traffic on routes where demand promises to be heavy in the foreseeable future. On the other hand, cables lack the flexibility that is desirable for the accommodation of shifting patterns of demand.

Second, the advantage of communications satellite systems, relative to conventional systems, once seemed to lie with overseas rather than overland routes. However, it now seems that for comparable capacities, overseas conventional costs and overland conventional costs are of the same order of magnitude. This finding suggests that the routes that could be served by satellite systems are not limited to overseas routes; for some land routes, at least, satellite costs might be lower than conventional costs.

Third, the cost advantage of communications satellite systems, relative to conventional systems, has often been thought to lie mainly with heavy-volume routes rather than light-volume routes (even though it has been recognized that the costs per channel of conventional (land) facilities on low-volume routes are very much greater than the costs of conventional (land) facilities on high-volume routes). Re-examination of the evidence suggests that this supposed advantage of communications satellites may have been accepted too easily.

All three of these considerations support our initial conclusion: There are significant advantages to be expected from attempts to increase our knowledge of ways of serving inexpensively low-volume as well as high-volume routes. Satellite research and development planning should take account of these advantages and, among other objectives, look for ways of providing inexpensive low-volume service (say, fewer than 100 channels) over many routes (say, more than fifty).

Appendix A

TASI AND CABLE SYSTEM COSTS

Time Assignment Speech Interpolation, or TASI, is a device that operates by taking advantage of pauses in conversation to use the temporarily idle channel for other calls. It was first used in 1960, and it has now been applied to the first two transatlantic cables, TAT-1 and TAT-2, to the California-Hawaii cable, and to the Florida-Puerto Rico cable.

In the circuits to which it is applied, TASI doubles the capacity for carrying telephone conversations. Existing TASI systems, which cost $3,000,000 each, are applied to a group of 37 voice channels, yielding a total of 74 trunks. In times of emergency, TASI systems are overloaded, and may provide as many as 90 trunks (from the original 37 channels).

The loss in quality of speech transmission due to the use of TASI is not ordinarily noticed by the customer. If the TASI system is being overworked, as in times of emergency, the loss of quality does become significant.

TASI has been applied only to submarine telephone cable channels reserved for telephone message service. It could be applied to private-line channels used for voice only. It is not suitable for application to channels leased to the telegraph companies or to private-line channels leased for alternative voice and record use.

In brief, in normal practice, TASI adds 37 voice trunks to the capacity of cable systems at a cost of $3,000,000 for the initial equipment, without significant reduction in the quality of speech transmission.

Hitherto, TASI has provided a relatively cheap means of increasing the message carrying capacity of overseas links. Cables of the length and type of TAT-1 and TAT-2 provide only 48 voice channels at an initial cost of about $40,000,000. TASI is also cheap in comparison with cables of the type of TAT-3. For a system length of 2000 miles, the cost of a TAT-3 type cable system is about $30,000,000 for 128 voice channels, or for 37 voice channels, about $9,000,000 -- three times the cost of TASI.

In comparison with the cost of high-capacity cables, TASI does not appear to be inexpensive. For a system length of 2000 miles, the 720-circuit cable system would provide a group of 37 circuits at a cost of about $2,300,000 each. For a system length of 3500 miles, the cable cost of a group of 37 circuits is $4,000,000, only one-third more than the cost of TASI. If this were the end of the story, TASI would not be used with high-capacity cables on links of less than 3,000 miles, and because of the loss in speech quality, it might not be used on high-capacity systems of any length. However, the cost advantages of high-capacity cables can be realized only if a great many additional circuits are required. The cost of adding only 100 circuits to any already existing communications link, with substantial voice channel capacity already installed, is of course much less with TASI than with an entirely new cable system.

In principle, TASI could be applied to overland systems and to communications satellite systems. However, it would not be an economical means of increasing message-carrying capacity in either application. There are less expensive means of augmenting capacity in these systems.

In summary:

1. TASI is an inexpensive means of augmenting the telephone message carrying capacity of all existing submarine telephone cable systems.

2. TASI is an inexpensive means of adding 100 or 200 additional trunks to a high-capacity submarine telephone cable system.

3. The cost per voice-trunk-mile of high-capacity cable systems is not dependent on the use or non-use of TASI.

Appendix B

SUBMARINE TELEPHONE CABLE COSTS

INVESTMENT COSTS PER CIRCUIT-MILE BY TYPE OF CABLE

In the text, we give a cost of $114 per circuit-mile for cables of British design and for cables of AT&T design that are now being placed.

We use $114 as the cost per circuit-mile of the current AT&T cables on the advice of AT&T. We would obtain an almost identical estimate of the cost per circuit-mile by dividing the AT&T estimates of the total costs of cable systems by the number of circuit-miles. These cable systems have a capacity of 128 (3-kc) voice channels. The cost per circuit-mile for the Hawaii-Japan cable to be completed in the summer of 1964 is slightly greater than $114 (5500 nautical miles at a total cost of $84,000,000), while the cost per circuit-mile for the transatlantic cable to be completed in October 1963 (TAT-3) is slightly less than $114 (3500 nautical miles for a total cost of $50,000,000).

We use $114 as the cost per circuit-mile of the British cables because this appears to be a reasonable estimate and because it is convenient to cite a single cost estimate for both British and American cables of current design. The British cables have a capacity of 80 (3-kc) voice channels. In 1962, a cable of British design was placed from New Jersey to Bermuda, 760 nautical miles, at a cost of $7,600,000, or a cost of $125 per circuit-mile. According to the cost figures supplied by Mr. Frederick Lee (quoted in the text), the cost per circuit-mile of the British system now being placed across the Pacific is $106. Our estimate, $114, is within the range from $106 to $125.

The cost we cite for the 720-voice-channel cable, $32 per circuit-mile, is AT&T's current estimate. It is of course a speculative developmental figure. If such a system is ever placed, the actual costs might be lower, or, perhaps more likely, higher. The estimate made in 1959 by the AT&T Long Lines Department of the cost of the type of cable system then under development was about 20 per cent less than the cost turned out to be.

The costs cited are the costs of the complete system, including costs of the cable itself and its placement, the repeaters (amplifiers), terminal stations, and general engineering expenses. For TAT-3, according to information supplied by AT&T, the costs of these various components are as follows:

3500 nautical miles of cable	$19,000,000	(38%)
192 repeaters	15,000,000	(30%)
2 terminal stations	5,500,000	(11%)
Engineering, placing the cable, and other	10,500,000	(21%)
Total	$50,000,000	(100%)

The costs cited do not include the costs of TASI equipments.

COST INDEXES, 1956-1967, HIGH-VOLUME ROUTES

In Section II of the text, we presented indexes of costs on high-volume routes for the period 1956-1967. For this period there are four relevant cable systems. The first is the first AT&T system, placed in service during the period 1956-1959. The second is the British system, placed on very long routes for the first time in 1961. The third is the second (or current) AT&T system, introduced in the spring of 1963. The fourth is the high-capacity, 720-voice-channel system.

The base figure for our indexes is the cost for the period 1956-1959, $450 per circuit-mile. This cost is the average cost of the cable systems that AT&T was placing at the time. These systems had a capacity of 36 4-kc voice channels.

In 1960, new channeling equipment was applied to the AT&T cable systems. The new equipment made possible the derivation from only 12 kc of cable bandwidth four channels equal in quality (except for a loss of 8 per cent in top frequencies) to the standard 4-kc voice channels. The capacity of the then existing AT&T systems was increased from 36 (4-kc) channels to 48 (3-kc) channels. Since 1960 (with some minor exceptions), cable capacity has been stated in terms of 3-kc voice channels. For example, the capacity of the current AT&T cable system, which has a frequency bandwidth of 400 kc (in each direction of transmission), is stated as 128 (3-kc) voice channels. The 720 channels of the high-capacity cable would be 3-kc channels.

For very broadband service (greater than 4 kc), the new channeling equipment is not of significance. The relevant trend in costs is the trend in the costs of bandwidth. This trend is equivalent to the trend in costs per 4-kc voice channel. Per 4-kc voice channel, the relative costs are $450 for the older AT&T system; (4/3)($114) = $152, or 33 per cent of $450, for the current British and American systems; and (4/3)($32) = $42.67, or 9.5 per cent of $450, for the 720-circuit cable.

For leased lines, the new channeling equipment is of significance. The relevant trend in costs is the trend in the costs of voice channels (whether 4 kc or 3 kc). The actual costs per mile are $450 for the older AT&T system; (3/4)($450) = $337.50, or 75 per cent of $450, for the older systems equipped with the new channeling equipment; $114, or 25 per cent of $450, for the current British and American systems; and $32, or 7 per cent of $450, for the transistorized cable.

For message telephone service costs, we take account of the application of TASI to the older AT&T cable systems and the potential application of TASI to the current British and American systems. For a route of 2000 nautical miles, TASI adds trunks at a cost of $40.54 per trunk-mile (see Appendix A). TASI was first applied to the older AT&T cable systems in 1960, after the introduction of the new channeling equipment. The effect was to reduce the cost of voice trunks from (3/4)($450) = $337.50 to the average of $337.50 and $40.54, ($337.50 + $40.54)(1/2) = $189.02, or 42 per cent of $450. The effect of the application of TASI to the current British and American systems will be to reduce the cost of voice trunks from $114 to the average of $114 and $40.54 -- ($114 + $40.54)(1/2) = $77.77, or 17 per cent of $450. The index number given in Section II of the text for costs of message telephone service in the period 1961-1965 takes into account the potential application of TASI.

Appendix C

EQUIVALENT LEVEL ANNUAL COSTS

In this Memorandum, we have calculated equivalent level annual costs as if (1) all investment costs are incurred at a single point in time, the moment when the facility is put in service, (2) operating and maintenance costs are incurred at a constant rate throughout the service life of the facility, and (3) the facility is used at full capacity from the moment it goes into service.

Let:

- r be the rate of discount
- I be the initial investment costs
- R be the recurring operating and maintenance costs
- t be the service life of the facility
- n be the number of channels provided, or channel miles

It is helpful to define a function, F, of r and t:

$$F(r,t) = r/(1-e^{-rt}).$$

Then the equivalent level annual cost per channel or per channel mile is:

$$[R + F(r,t)I]/n.$$

In the case of microwave systems, the service life of the radio component is not the same as the service life of the channelization component. Let I_1 and t_1 be the investment cost and the service life, respectively, of the radio component; let I_2 and t_2 be the investment cost and the service life, respectively, of the channelization equipment. Then the annual cost per channel or per channel mile is given by:

$$[R + F(r,t_1)I_1 + F(r,t_2)I_2]/n.$$

These formulae differ in appearance from those used in previous cost calculations for NASA.* The difference in appearance arises

---

*For example, W. H. Meckling, Communications Satellites: Supplemented Information on the Cost Estimates given in RM-2709-NASA, The RAND Corporation, RM-2778-NASA, June 1961.

because in the present Memorandum we have treated maintenance outlays, for example, as being incurred continuously rather than as being incurred at one lump at the end of the year. Aside from this minor modification, the formulae are logically identical to those explained and adopted in the work just cited.

To give an example of the use of the formulae, we will calculate the cost per channel mile per year for a landline microwave system of 720-voice-channel capacity, providing point-to-point service between terminals 2000 miles apart. The investment cost per (statute) mile for the radio equipment is about $5,000, and the service life is 15 years. The investment cost for the channelization equipment is $1,440,000, or $720 per mile, and the service life is 20 years. Annual operating and maintenance costs of the radio equipment are 10 per cent of investment costs, or $500 per mile per year; annual operating and maintenance costs of the channelizing equipment are 8 per cent of investment costs, or $57.60 per mile per year. The costs and service lives are estimates supplied by AT&T. We take the rate of discount to be 15 per cent per year.

We compute:

$$F(.15,15) = .15/(1 - e^{-2.25}) = .1677$$

$$F(.15,20) = .15/(1 - e^{-3.00}) = .1579$$

Hence, the cost per channel mile per year is:

$$\frac{500 + 57.60 + (5000)(.1677) + (720)(.1579)}{720} = \$2.10$$

Because submarine telephone cable costs are expressed as costs per nautical mile, we want for comparative purposes landline costs per nautical mile. The cost per channel per statute mile is $2.10; the cost per channel per nautical mile is $2.42. In the text, we round this figure off to $2.40.

Appendix D

NORTH ATLANTIC TELEPHONE CABLE ROUTES AND CABLE SYSTEM COSTS

The route followed by the first two transatlantic cable systems (TAT-1 and TAT-2) between the United States and Europe is a great circle route: overland from New York to Nova Scotia, a 325-mile cable link from Nova Scotia to Newfoundland, and a 2000-mile cable link from Newfoundland to landfall in Western Europe (Oban, Scotland, and Penmarch, France).

The 1963 transatlantic cable (TAT-3) goes directly from Tuckerton, New Jersey, undersea all the way in deep water, to Cornwall in Britain. The 1965 transatlantic cable (TAT-4) will also go undersea all the way in deep water, from Tuckerton to Brittany in France. The distance is about 3500 nautical miles.

At first glance, the Newfoundland route seems to be preferable to the deep-sea route. Via Newfoundland, there is less submarine cable and more landline, and landline is cheaper than cable. However, because of breaks in the cables caused by trawlers and icebergs, the Newfoundland route is both more expensive to maintain and also less useful. Neither trawlers nor icebergs should be a problem on the TAT-3 and TAT-4 routes.

The fact that the deep-sea route has been chosen for TAT-3 and TAT-4, in preference to the Newfoundland route, suggests that the deep-sea route will also be chosen for the high-capacity cable systems of the future.

It follows that the cost of a high-capacity cable system between the United States and Western Europe will be the cost of a system of length 3500 nautical miles. With 720 voice channels, and an installation cost of $32 per nautical mile, the total cost is about $80,000,000.

The route of the CANTAT cable, which runs from Canada to the United Kingdom via Newfoundland, was chosen in the expectation that it would be relatively free from damage by trawlers. However, although the cable has been in operation for somewhat less than two years, a number of trawler breaks have already occurred. This experience tends to increase the likelihood that a 720-circuit cable would follow a deepsea route.

BIBLIOGRAPHY

The following list is restricted to references that were especially useful in the present study.

I. Book-length Studies

Buyers, John William Amerman, Wings of the Morning, An Analysis of Space Communications and Its Future, a dissertation submitted to the School of Industrial Management, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1963.

Fields, David S., On the Business Potential of Telephone Service Via a Man-Made Satellite System, a dissertation submitted to The American University, Washington, D.C., 1963 (copyright by David S. Fields, Santa Barbara, California).

II. Publications of The RAND Corporation (RAND Memoranda)

Klein, B. H., et al., Communications Satellites and Public Policy: An Introductory Report, RM-2925-NASA, December 1961.

Meckling, W., Communications Satellites: Supplemental Information on the Cost Estimates Given in Research Memorandum RM-2709-NASA, RM-2778-NASA, June 1961.

Minasian, J., Telephone Rates, Queues, Costs: Some Economic Implications for Analyzing Fluctuating Demands, RM-3829-NASA, September 1963.

Nichols, R. T., Submarine Telephone Cables and International Telecommunications, RM-3472-RC, February 1963.

Reiger, S. H., et al., Communications Satellites: Technology, Economics, and System Choices, RM-3487-RC, February 1963.

Slighton, R., The Market for Overseas Telecommunications in 1970, RM-3831-NASA, September 1963.

Slighton, R., Overseas Telecommunications Traffic and Commodity Trade, RM-3817-NASA, September 1963.

III. Papers by Members of The RAND Corporation

Johnson, L. L., "The Commercial Uses of Communication Satellites," California Management Review, Spring 1963, Vol. V, No. 3, pp. 55-66.

-----, Joint Cost and Price Discrimination: The Case of Communications Satellites, The RAND Corporation, P-2753-1, July 1963.

Meckling, W., "Economic Potential of Communication Satellites," Science, June 16, 1961, Vol. 133, No. 3468, pp. 1885-1892.

Reiger, S. H., and W. Meckling, Economic Aspects of Communication Satellite Systems, The RAND Corporation, P-2396, August 1961 (presented at the International Symposium on Space Communication sponsored by URSI in Paris, September 1961.

IV. Other Publications

Ad Hoc Carrier Committee, Report of the Ad Hoc Carrier Committee, October 12, 1961 (part of Docket No. 14024 of the Federal Communications Commission).

American Telephone & Telegraph Co., The Bell System Technical Journal, New York, bimonthly. In particular, for an account of the development of the first transatlantic telephone cable, see the January 1957 issue (in its entirety) and the September 1957 issue, pp. 1047-1207. For a discussion of TASI, see the July 1962 issue, pp. 1439-1473.

-----, "Estimated Overseas Telephone Message Traffic, 1960," October 1961, mimeographed. (The anonymous author is H. M. Flinn.)

-----, "Frequency Needs for Space Communication," July 6, 1960, (testimony and exhibits of four AT&T representatives before the Federal Communications Commission, Docket No. 11866).

Halsey, R. J., "Transatlantic Cables for Television," British Communications and Electronics, August 1963, pp. 620-624.

McMillan, William, "Packing More Telephone Calls into Trunk Cables," The New Scientist, 28 July 1960, pp. 275-277. (Valuable, inter alia, for the discussion of the channelizing development that permits the reduction of bandwidth required per voice channel from 4 to 3 kc.)

Telecommunication Reports, Washington, D.C., weekly.

United States Government, 88th Congress, 1st Session, Satellite Communications, Hearings before the Subcommittee on Communications of the Committee on Commerce, United States Senate, February 18, 19, and 27, 1963, U.S. Government Printing Office, Washington, 1963. (Pages 38 and 39 are especially relevant.)